

What is claimed is:

1. A method of making a pultruded part having a uniform cross-section, the method comprising the steps of:

orienting a plurality of longitudinal rovings along a longitudinal axis  
5 of a pultrusion die;

providing a reinforcing structure comprising a permeable transport web of staple fibers attached to a plurality of first reinforcing fibers oriented so that the portion of the first reinforcing fibers oriented in a direction transverse to the longitudinal axis comprises at least 40% of a volume of materials comprising the  
10 reinforcing structure;

shaping the reinforcing structure to generally conform with a profile of the pultrusion die;

combining a resin matrix with the longitudinal rovings and the reinforcing structure in the pultrusion die so that the longitudinal rovings and the  
15 reinforcing structure are substantially surrounded by the resin matrix;

at least partially curing the resin matrix in the pultrusion die; and  
pulling the pultruded part from the pultrusion die.

2. The method of claim 1 wherein the portion of the first  
20 reinforcing fibers oriented in the direction transverse comprises at least 50% of a volume of materials comprising the reinforcing structure.

3. The method of claim 1 wherein the first reinforcing fibers  
comprise one or more overlapping layers of first reinforcing fibers.

25 4. The method of claim 1 comprising preparing the cut staple fibers to have a length of about ½ inch to about 4 inches.

5. The method of claim 1 comprising preparing the cut staple fibers to have a length of about 0.01 inch to about 12 inches.

6. The method of claim 1 comprising preparing the cut staple fibers to have a weight of about 60 grams per square meter to about 300 grams per square meter before attachment to the first reinforcing fibers.

7. The method of claim 1 comprising preparing the cut staple fibers to have a weight of about 10 grams per square meter to about 1200 grams per square meter before attachment to the first reinforcing fibers.

8. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeable transport web from heat-fusible fibers.

9. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeable transport web from at least two different polymeric fibers each with different glass transition temperature.

10. The method of claim 9 wherein the at least two polymeric fibers comprise a glass transition temperature of about 350°F and about 270°F, respectively.

11. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeable transport web from a plurality of first polymeric fibers comprising a first glass transition temperature, and a plurality of bi-component fiber wherein a first component comprises the first glass

transition temperature, and a second component comprises a second glass transition temperature less than the first glass transition temperature.

12. The method of claim 11 wherein the bi-component fibers  
5 comprise a core-sheath configuration.

13. The method of claim 1 wherein the step of providing the  
reinforcing structure comprises preparing the reinforcing structure to have  
substantially in-plane mechanical and directional stability.  
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14. The method of claim 1 wherein the step of providing the  
reinforcing structure comprises randomly entangling at least a portion of fibers in  
the permeable transport web with the first reinforcing fibers.

15. The method of claim 1 wherein the step of providing the  
reinforcing structure comprises thermally bonding at least a portion of fibers in the  
permeable transport web with the first reinforcing fibers.  
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16. The method of claim 1 comprising attaching the first  
20 reinforcing fibers in a spaced-apart configuration with a continuous stitching fiber.

17. The method of claim 16 wherein the stitching fiber comprises  
glass fibers, natural fibers, carbon fibers, metal fibers, ceramic fibers, synthetic or  
polymeric fibers, composite fibers (including one or more components of glass,  
25 natural materials, metal, ceramic, carbon, and/or synthetics components), or a  
combination thereof.

18. The method of claim 1 wherein the step of providing the reinforcing structure comprises applying a binder to the permeable transport web and the first reinforcing fibers.

5 19. The method of claim 18 wherein the binder comprises one or more of a specialized latex binder diluted in a water carrier, a polyvinyl acetate emulsion, and a crosslinking polyvinyl acetate emulsion.

10 20. The method of claim 1 wherein the step of providing the reinforcing structure comprises forming a plurality of perforations through the permeable transport web and between the first reinforcing fibers.

15 21. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a permeability of at least  $180 \text{ ft}^3/\text{minute}/\text{ft}^2$  as measured according to the procedure of ASTM D737-96 with a pressure differential of about 0.5 inch column of water.

20 22. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a permeability of about  $300 \text{ ft}^3/\text{minute}/\text{ft}^2$  as measured according to the procedure of ASTM D737-96 with a pressure differential of about 0.5 inch column of water.

25 23. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a permeability of more than  $350 \text{ ft}^3/\text{minute}/\text{ft}^2$  as measured according to the procedure of ASTM D737-96 with a pressure differential of about 0.5 inch column of water.

24. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a circular bending stiffness of at least about 4 Newtons as measured according to the procedure of ASTM D4032-94.

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25. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a circular bending stiffness in a range of at least about 4 Newtons to about 15 Newtons as measured according to the procedure of ASTM D4032-94.

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26. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a thickness of about 0.004 inches to about 0.020 inches.

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27. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a thickness of about 0.010 inches to about 0.012 inches.

28. The reinforcement structure of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a tensile strength in the transverse direction of about 200 lbs/inch as measured using the procedure of ASTM D76-99.

29. The reinforcement structure of claim 1 wherein the step of providing the reinforcing structure comprises preparing the permeably reinforcing sheet with a tensile strength along the longitudinal axis of at least 6 lbs/inch as measured using the procedure of ASTM D76-99.

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30. The method of claim 1 wherein the step of providing the reinforcing structure comprises selecting the first reinforcing fibers from a group consisting of glass fibers, natural fibers, carbon fibers, metal fibers, ceramic fibers, synthetic or polymeric fibers, composite fibers (including one or more components of glass, natural materials, metal, ceramic, carbon, and/or synthetics components), or a combination thereof.

31. The method of claim 1 wherein the step of providing the reinforcing structure comprises preparing the first reinforcing fibers with at least one polymeric component.

32. The method of claim 1 wherein the step of providing the reinforcing structure comprises coating the first reinforcing fibers with a surface treatment including an organosilane agent.

33. The reinforcement structure of claim 32 wherein the organosilane agent comprises one or more families of a cationic amino-functional silane, Tris (2- methoxyethoxyvinylsilane), or 3-methacryloxypropyltrimethoxysilane.

34. The method of claim 1 wherein the step of providing the reinforcing structure comprises arranging the first reinforcing fibers in a direction about  $90^{\circ} \pm 10^{\circ}$  relative to the longitudinal axis.

35. The method of claim 1 wherein the step of providing the reinforcing structure comprises arranging the first reinforcing fibers in a direction about  $90^{\circ} \pm 5^{\circ}$  relative to the longitudinal axis.

36. The method of claim 1 wherein the step of providing the reinforcing structure comprises arranging substantially all of the first reinforcing fibers to extend continuously across a width of the reinforcing structure.

5 37. The method of claim 1 wherein the step of providing the reinforcing structure comprises attaching a plurality of permeable transport webs to the first reinforcing fibers.

10 38. The method of claim 1 wherein the step of providing the reinforcing structure comprises arranging a plurality of second reinforcing fibers at one or more acute angles relative to the longitudinal axis.

15 39. The method of claim 1 wherein the step of providing the reinforcing structure comprises arranging a plurality of second reinforcing fibers at a first acute angle relative to the longitudinal axis and arranging a plurality of third reinforcing fibers at a second acute angle that is the negative of the first acute angle.

20 40. The method of claim 39 wherein the step of providing the reinforcing structure comprises arranging a plurality of fourth reinforcing fibers parallel to the longitudinal axis.

25 41. The method of claim 39 wherein the step of providing the reinforcing structure comprises locating the first reinforcing fibers between the second and third reinforcing fibers.

42. The method of claim 1 wherein the step of providing the reinforcing structure comprises the steps of:

arranging a plurality of second reinforcing fibers at a first acute angle relative to the pull direction;

arranging a plurality of third reinforcing fibers at a second acute angle that is the negative of the first acute angle; and

5 arranging a plurality of fourth reinforcing fibers generally in the pull direction.

43. The method of claim 42 wherein the step of providing the reinforcing structure comprises randomly entangling at least a portion of fibers in  
10 the permeable transport web with one or more of the first, second, third or fourth reinforcing fibers.

44. The method of claim 42 wherein the step of providing the reinforcing structure comprises thermally bonding at least a portion of fibers in the  
15 permeable transport web with one or more of the first, second, third or fourth reinforcing fibers.

45. The method of claim 42 wherein the step of providing the reinforcing structure comprises stitching the first reinforcing fibers to one or more of  
20 the permeable transport web, the second reinforcing fibers, the third reinforcing fibers, and the fourth reinforcing fibers.

46. The method of claim 42 wherein the step of providing the reinforcing structure comprises applying a binder to the permeable transport web  
25 and to one or more of the first, second, third or fourth reinforcing fibers.



47. The method of claim 42 wherein the step of providing the reinforcing structure comprises preparing one or more of the first, second, third or fourth reinforcing fibers with a polymeric component.

5 48. The method of claim 42 wherein the step of providing the reinforcing structure comprises locating the first reinforcing fibers between the second and third reinforcing fibers and the fourth reinforcing fibers.

10 49. The method of claim 42 wherein the step of providing the reinforcing structure comprises preparing the first, second, third or fourth reinforcing fibers as discrete layers.

15 50. The method of claim 1 comprising the step of attaching the reinforcing structure to the longitudinal rovings prior to combining with the resin matrix.

20 51. The method of claim 1 comprising the step of positioning a plurality of longitudinal rovings along each surface of the reinforcing structure prior to combining with the resin matrix.

52. The method of claim 1 comprising the step of positioning the reinforcing structure adjacent to a surface of the pultruded part.

25 53. The method of claim 1 comprising the step of positioning the longitudinal rovings adjacent to a surface of the pultruded part.

54. The method of claim 1 comprising the step of arranging alternating layers of reinforcing structure and longitudinal rovings prior to combining with the resin matrix.

5 55. A method of making a pultruded part having a uniform cross-section, the method comprising the steps of:

orienting a plurality of longitudinal rovings along a longitudinal axis of a pultrusion die;

providing a reinforcing structure comprising a plurality of first  
10 reinforcing fibers oriented in a direction transverse to the longitudinal axis attached to a permeably reinforcing sheet, the permeably reinforcing sheet comprising a plurality of first polymeric fibers comprising a first glass transition temperature and a plurality of bi-component fiber wherein a first component comprises the first glass transition temperature and a second component comprises a second glass transition  
15 temperature less than the first glass transition temperature;

shaping the reinforcing structure to generally conform with a profile of the pultrusion die;

combining a resin matrix with the longitudinal rovings and the reinforcing structure in the pultrusion die so that the longitudinal rovings and the  
20 reinforcing structure are substantially surrounded by the resin matrix;

at least partially curing the resin matrix in the pultrusion die; and  
pulling the pultruded part from the pultrusion die.

56. A method of making a pultruded part having a uniform cross-section, the method comprising the steps of:

orienting a plurality of longitudinal rovings along a longitudinal axis of a pultrusion die;

providing a reinforcing structure comprising a plurality of first reinforcing fibers oriented in a transverse direction thermally bonded to a permeably reinforcing sheet so that the reinforcing structure comprises a permeability of at least 180 ft<sup>3</sup>/minute/ft<sup>2</sup> as measured according to the procedure of ASTM D737-96

5 with a pressure differential of about 0.5 inch column of water;

shaping the reinforcing structure to generally conform with a profile of the pultrusion die;

combining a resin matrix with the longitudinal rovings and the reinforcing structure in the pultrusion die so that the longitudinal rovings and the reinforcing structure are substantially surrounded by the resin matrix;

at least partially curing the resin matrix in the pultrusion die; and  
pulling the pultruded part from the pultrusion die.

57. A method of making a pultruded part having a uniform cross-section, the method comprising the steps of:

orienting a plurality of longitudinal rovings along a longitudinal axis of a pultrusion die;

providing a reinforcing structure comprising a plurality of first reinforcing fibers oriented in a transverse direction attached to a permeable transport web of staple fibers such that a ratio of a modulus of elasticity of the reinforcing structure in the transverse direction relative to a modulus of elasticity in the pull direction comprises at least 1.2;

shaping the reinforcing structure to generally conform with a profile of the pultrusion die;

combining a resin matrix with the longitudinal rovings and the reinforcing structure in the pultrusion die so that the longitudinal rovings and the reinforcing structure are substantially surrounded by the resin matrix;

at least partially curing the resin matrix in the pultrusion die; and

pulling the pultruded part from the pultrusion die.

58. The method of claim 57 wherein the ratio of the modulus of elasticity of the reinforcing structure in the transverse direction relative to the modulus of elasticity in the pull direction comprises at least 1.5.

59. The method of claim 57 wherein the ratio of the modulus of elasticity of the reinforcing structure in the transverse direction relative to the modulus of elasticity in the pull direction comprises at least 3.

60. The method of claim 57 wherein the ratio of the modulus of elasticity of the reinforcing structure in the transverse direction relative to the modulus of elasticity in the pull direction comprises at least 5.

61. A method of making a pultruded part having a uniform cross-section, the method comprising the steps of:

orienting a plurality of longitudinal rovings along a longitudinal axis of a pultrusion die;

providing a reinforcing structure comprising a permeable transport web of staple fibers attached to a plurality of non-overlapping first reinforcing fibers oriented so that the portion of the first reinforcing fibers oriented in a direction transverse to the longitudinal axis comprises at least 30% of a volume of materials comprising the reinforcing structure;

shaping the reinforcing structure to generally conform with a profile of the pultrusion die;

combining a resin matrix with the longitudinal rovings and the reinforcing structure in the pultrusion die so that the longitudinal rovings and the reinforcing structure are substantially surrounded by the resin matrix;

at least partially curing the resin matrix in the pultrusion die; and  
pulling the pultruded part from the pultrusion die.

62. A method of making a pultruded part having a uniform cross-  
5 section, the method comprising the steps of:

orienting a plurality of longitudinal rovings along a longitudinal axis  
of a pultrusion die;

providing a reinforcing structure comprising a plurality of first  
reinforcing fibers oriented at  $45^{\circ}$  (+/-  $15^{\circ}$ ) relative to the pull direction, a plurality of  
10 second reinforcing fibers oriented at  $-45^{\circ}$  (+/-  $15^{\circ}$ ) relative to the pull direction, and  
a permeable transport web of staple fibers attached to the first and second  
reinforcing fibers such that the first and second reinforcing fibers comprises at least  
30% of a volume of materials comprising the reinforcing structure;

shaping the reinforcing structure to generally conform with a profile  
15 of the pultrusion die;

combining a resin matrix with the longitudinal rovings and the  
reinforcing structure in the pultrusion die so that the longitudinal rovings and the  
reinforcing structure are substantially surrounded by the resin matrix;

at least partially curing the resin matrix in the pultrusion die; and  
20 pulling the pultruded part from the pultrusion die.

63. A method of making a pultruded part having a uniform cross-  
section, the method comprising the steps of:

orienting a plurality of longitudinal rovings along a longitudinal axis  
25 of a pultrusion die;

providing a reinforcing structure comprising a plurality of first  
reinforcing fibers oriented at  $60^{\circ}$  (+/-  $15^{\circ}$ ) relative to the pull direction, a plurality of  
second reinforcing fibers oriented at  $-60^{\circ}$  (+/-  $15^{\circ}$ ) relative to the pull direction, and

a permeable transport web of staple fibers attached to the first and second reinforcing fibers such that the first and second reinforcing fibers comprises at least 30% of a volume of materials comprising the reinforcing structure;

5       shaping the reinforcing structure to generally conform with a profile of the pultrusion die;

          combining a resin matrix with the longitudinal rovings and the reinforcing structure in the pultrusion die so that the longitudinal rovings and the reinforcing structure are substantially surrounded by the resin matrix;

10       at least partially curing the resin matrix in the pultrusion die; and pulling the pultruded part from the pultrusion die.

64.     A method of making a molded part having a longitudinal axis, the method comprising the steps of:

15       providing a reinforcing structure comprising a permeable transport web of staple fibers attached to a plurality of first reinforcing fibers oriented so that the portion of the first reinforcing fibers oriented in a direction transverse to the longitudinal axis comprises at least 40% of a volume of materials comprising the reinforcing structure;

20       shaping the reinforcing structure to generally conform with a die; combining a resin matrix with the reinforcing structure in the die so that the reinforcing structure is substantially surrounded by the resin matrix; at least partially curing the resin matrix in the die; and removing the molded part from the die.

25       65.     A method of making a pultruded part having a uniform cross-section, the method comprising the steps of:

          orienting a plurality of longitudinal rovings along a longitudinal axis of a pultrusion die;

providing a reinforcing structure comprising a permeable transport web of staple fibers attached to a plurality of first reinforcing fibers oriented in a transverse direction continuously across a width of the reinforcing structure;

5       shaping the reinforcing structure to generally conform with a profile of the pultrusion die;

          combining a resin matrix with the longitudinal rovings and the reinforcing structure in the pultrusion die so that the longitudinal rovings and the reinforcing structure are substantially surrounded by the resin matrix;

10       at least partially curing the resin matrix in the pultrusion die; and  
          pulling the pultruded part from the pultrusion die.